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Assessment of the NASA AvSTAR Project Plan

Michael L. Ulrey, Aslaug Haraldsdottir, Matthew E. Berge, Craig A. Hopperstad, and Robert W. Schwab

July 2004

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1. Introduction

This report documents work performed by Boeing Air Traffic Management for the NASA Ames Research Center. The work was contracted through the Federal Aviation Administration's (FAA's) Office of System Capacity & Requirements support services contract with ATAC Corporation. The purpose of this contract work was to perform a preliminary evaluation of NASA's proposed Aviation System Technology Advanced Research Program (AvSTAR) during the early stages of its definition, in the first half of the year 2001.

The scope of work specified by the NASA Ames AvSTAR program office was as follows:

> NASA's Ames Research Center has proposed a new initiative/program in Air Traffic Management (ATM) called the Aviation System Technology Advanced Research Program (AvSTAR). AvSTAR's goal is to provide research and development by the year 2007 that will: (1) complete the development of technology needed to enable Free-Flight by 2010 and (2) provide the basic R&D foundation to set the direction for ATM as a high-capacity, integrated component of a multi-modal transportation system of the future (circa 2025). AvSTAR has an aggressive list of quantifiable objectives/metrics for both of the target time frames (2010 and 2025).
>
> The Subcontractor shall perform an independent review of the current AvSTAR proposal to provide a risk assessment of the proposed program content against the AvSTAR system performance goals. Recommendations on how the AvSTAR program could be strengthened and improved shall also be provided. The review shall be based on expert knowledge of the current and near term ATM system and a high level assessment to estimate the potential impact of AvSTAR derived technology on the ATM system in the years 2010 and 2025. The task will involve coordination with NASA personnel and up to two other NASA support contractors.

In the context of this scope of work, NASA requested that Boeing ATM focus the AvSTAR assessment on providing answers to the following three questions:

1. <u>Goals</u>: Are the stated AvSTAR goals complete and correct with respect to the needs of the U.S. National Airspace System (NAS) for the stated timeframe? In other words, do the goals address the real needs of the NAS, and are there any additional goals that should be included?
2. <u>Feasibility</u>: Are the goals technically feasible; i.e., could they be achieved in the given timeframe if adequate resources were allocated?
3. <u>Plan</u>: Does the AvSTAR project plan provide the technical direction, resources, and coordination necessary to achieve the goals in the given time?

The approach of the Boeing team in gathering information was to attend the AvSTAR government/industry workshops held in September 2000 and March 2001, hold teleconferences with AvSTAR personnel (weekly or biweekly), and analyze AvSTAR project presentation materials. The Boeing team also conducted regular internal meetings in order to discuss findings and recommendations. Finally, an air traffic demand-capacity study using the Boeing Current Market Outlook (CMO) was performed to provide an initial assessment of the feasibility of the NASA goals. This work was performed jointly by the Mathematics and Computing Division of Phantom Works (Boeing's research organization) and Boeing's CMO organization.

This report is organized around the three questions that were addressed, with the goals stated in section 2, and analysis and answers presented in sections 3–5. Section 6 presents summary conclusions and recommendations for the AvSTAR project office, and appendices A and B present further details supporting the definition of demand, throughput, delay, and the CMO-based analysis performed.

2. Goals

The objectives and goals of the AvSTAR project, as defined in the presentation by Dallas Denery at the March 2001 workshop [1], are:

Objectives:
Provide the research and development by 2007 necessary to:
1. Complete the development of technology for tomorrow (Free Flight).
2. Provide the foundations for setting the future direction (Beyond Free Flight).

Goals:
Tomorrow's Air Transportation System (2010)
1. 22-percent increase in throughput at high-density airports
2. 25-percent reduction in today's missed/cancelled flights due to traffic problems
3. 25-percent reduction in average delay

The Future Air Transportation System (2025)
1. 64-percent increase in throughput at high-density airports
2. 50-percent reduction in missed/cancelled flights
3. 50-percent reduction in average delay

Finally, in this project, air transportation is viewed as one component of a fully integrated multi-modal transportation system.

3. Are the Goals Complete and Correct?

The throughput goals are lower than the increase in demand predicted by the Boeing Current Market Outlook 2000 [2]. The NASA figures of 22-percent and 64-percent increases for 10 and 25 years, respectively, are based on a 2-percent average annual increase in air traffic. The Boeing CMO for the next 10 years currently predicts a 2.8-percent annual increase in revenue passenger kilometers (RPKs) for the North American region, leading to a total increase in departures of 77 percent by 2020. This includes Canada, but over 90 percent of the flights are U.S. based. Also, this does not include international flights that either originate or terminate in the U.S., which have been growing at a somewhat higher rate over the last decade.

Recommendation 1. Revise the 2-percent growth assumption in the goals statement related to projected increases in future traffic demand. See Recommendation 5 for additional details.

The AvSTAR project schedule for the completion of research to support these goals is about right: finish the research for the 2010 goals by 2007 and finish research for the 2025 goals by 2015. Based on the length of time between the end of each research phase and the corresponding start of implementation, the authors recommend achieving a technology readiness level (TRL) of at least 6 by the end of the 2007 phase (for 2010 goals) and a TRL of at least 4 at the end of the 2015 phase (for 2025 goals). (Note: The March 2001 plan provided only for advanced component technologies to go to TRL 1 or 2. The proposed AvSTAR augmentation plan is structured to achieve TRL 4 by 2007.)

Recommendation 2. The schedule is aligned with the growth assumption. However, a clearer distinction needs to be made between the NASA research goals and the NAS implementation goals.

The goal statements would be better understood if they were accompanied by definitions of the basic concepts and metrics used (demand, throughput, and delay), and their relationships. Appendix A discusses how these terms could be defined to avoid ambiguous interpretation and potential difficulty in demonstrating that the goals will be met.

Recommendation 3. Clearly define the metrics used for goals.

One may ask if an unqualified increase in average system throughput will, in fact, result in a large proportion of passengers being able to fly when and where they want. Boeing performed a study, described in more detail in appendix B, which shows how future air carrier flight schedules are likely to become distorted if demand continues to increase but capacity does not. This study shows one estimate of the effect on “schedule quality” (a simple measure of whether or not passengers can fly when they want to) as a function of varying future capacity growth at today’s high-density airports. As demand increases over the next few years, with little or no corresponding increase in capacity, a greater portion of the passengers will be forced to depart or arrive at undesirable times of day. Undesirable times are determined from a standard Boeing plot of passenger preferences (shown in Figure B.3-1 and discussed in more detail in appendix B).

The analysis indicates that if NASA’s throughput goals were met, there would be no significant change in this schedule quality value at Chicago, Atlanta, or anywhere across the whole NAS. Relative to this schedule quality metric, the AvSTAR goals seem to be aligned with the currently predicted growth in demand. As discussed in appendix B, this simple schedule quality metric does not capture the complexity of passenger time-of-day travel preferences and constraints (particularly for the business traveler), but is only a first-order indication of throughput goal adequacy.

Recommendation 4. Link the throughput goals to metrics of passenger (and other user) preferences and include studies to quantify performance against such metrics.

The NASA throughput goals are based on industry predictions of future growth in demand for air traffic. As pointed out at the beginning of this section, the Boeing CMO differs in growth-rate prediction from the assumption made for establishing the current AvSTAR throughput goals. One thing is certain: all traffic growth predictions have been incorrect in one aspect or another. To hedge against the difficulty in forecasting traffic growth, the AvSTAR program should consider a range of forecasts, generated by making several different assumptions about the primary factors that influence growth. These factors include economic growth in different regions of the NAS, airline business and operational strategies, airplane size and performance mix, policy decisions that affect other modes of transportation, and so on. These future scenarios can result in significantly different future traffic patterns, for which NASA should attempt to have a robust set of solutions.

Recommendation 5. Look at a range of potential future scenarios, and tailor the goals and project plan to accommodate them.

Two factors that should be considered in the goal-setting process are *other (i.e., non-NASA) projected improvements to the NAS* and *technical risk*. It might be possible to scale back the AvSTAR goals somewhat based on predicted capacity increases from initiatives outside NASA's scope. Conversely, it might be necessary to make the goals more ambitious to compensate for the possibility that some concepts or technologies have a significant likelihood of not being implemented.

On the favorable side of this question, consider, for example, potential new runway construction occurring in the given timeframe. This is an example of a system capacity factor outside NASA's project scope. Figure 1 shows runways as one of several places on a particular flight where bottlenecks might occur. The FAA Operational Evolution Plan (OEP) [3] states that new runways will be constructed at 15 airports between now and 2010 (ATL, IAH, DFW, PHX, IAD, STL, DTW, CVG, MSP, MIA, SEA, MCO, CLT, DEN, and BOS). The new runway at Boston will be used only in special circumstances, so it is not considered a basic capacity increase factor. The new runways at the 14 remaining airports are projected to produce an average capacity increase of 28 percent per airport in visual meteorological conditions (VMC) and 37 percent per airport in instrument meteorological conditions (IMC). The FAA's OPSNET database shows that these 15 airports handle about 30 percent of the operations recorded per year at the top 99 airports in the NAS. This runway investment plan should be analyzed to produce an estimate of the capacity increase benefit across the entire system and thus on the NASA ATM system throughput goals.

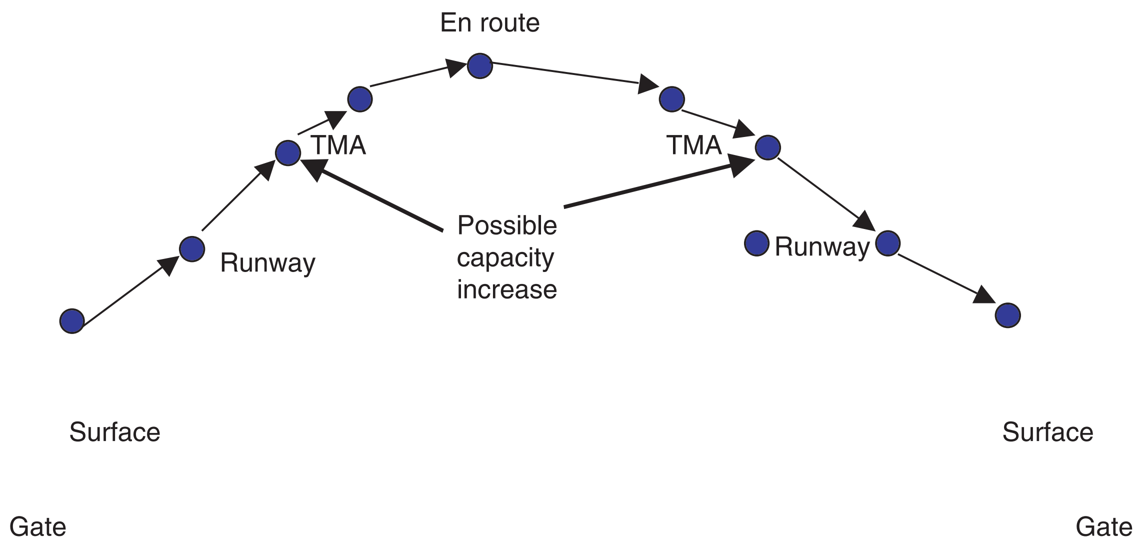

Figure 1. Potential System Bottlenecks.

Runways, however, are not the only NAS resource that can pose a constraint to traffic flow, and Figure 1 illustrates numerous other operational regions that also must be considered. Of those, NASA's primary research and development charter is in the management of surface, Traffic Management Advisor (TMA), and en-route areas, all of which have been shown to contribute to some portion of the predicted capacity shortfall. If a sufficient number of runways were added to the system to handle the growth, would this be sufficient to ensure overall system throughput with low levels of delay? The concern is that it would not, that, in fact, the TMA and en-route airspace will soon become the primary bottleneck in many areas of the NAS, or that at the largest airports, surface movement capacity would limit the actual throughput increase achievable with new runways.

Therefore, the translation of the overall AvSTAR throughput, delay, and cancellation goals into performance objectives for the various system operating regions is not straightforward, and *an early project activity needs to provide a clear understanding of what improvements are needed and where they should be implemented.* It may be possible to scale back on the performance goals for one operating region, while the need for another might be even greater than what is now predicted. The tools used in the Boeing demand-capacity study described in appendix B, as well as other national analysis tools that consider only airport capacity, are inadequate to provide insight into the required regional performance goals, as discussed in the Boeing paper "ATM Operational Concepts and Technical Performance Requirements" [4]. *The AvSTAR project should have such total system performance tools developed in the first phase of work, and apply them to establishing specific performance goals for the operating regions for which the project has been given research charter. This will require an initial focus on the development and integration of fast-time modeling and assessment tools that can address total system performance.*

Recommendation 6. Performance goals for particular operating regions need to be based on a total system performance analysis and an allocation of performance requirements to each operating region.

The high-level system throughput goal does not address the various capacity levels of the current NAS under different operating conditions, which contribute most significantly to the delay and cancellation performance goals. Allocation of throughput and/or delay goals to major weather categories such as IMC, VMC, and convective weather may be necessary to ensure that various technology solutions deliver a robust overall system performance. Appendix B illustrates that some of the predicted traffic growth may be accommodated by "filling in" the current off-peak times in the airline schedule. Considering that the schedule is based largely on the good VMC performance at each airport, it is clear that a schedule that is saturated at the VMC capacity level throughout the day has no room to recover from periods of poor weather. *To achieve the delay and cancellation reduction goals, it is imperative that the difference in VMC and IMC performance levels be kept to a reasonable minimum, limited primarily by considerations of single-flight safety concerns.*

Recommendation 7. Define performance goals for particular operating conditions, such as IMC Category I, II, and III, and convective weather. These goals should be as close as possible to the VMC goals, and they should be derived from the delay and cancellation goals.

Technical implementation risk is another concern that the AvSTAR project plan should account for in setting goals, as well as in the overall project execution. One possible approach to accounting for implementation risk would be to set the system performance goals somewhat higher than what is predicted to be needed. This way, if certain elements of the solution set are not successfully implemented, the end result has a higher probability of meeting the system need. Care should be taken not to set the mark so high that a solution becomes infeasible, and to make adjustment during execution of the project to continue tracking toward the goals.

Safety is mentioned in several AvSTAR presentations, but in the authors' opinion it is not given nearly enough emphasis. Capacity and safety are inextricably intertwined, and an effort to increase one may, if care is not taken, result in decrement to the other. Given the safety-critical nature of the air transportation system, and the agreed high level of safety demanded by the traveling public, it is imperative that all research and development for ATM be performed with a clear safety goal in mind. Safety requirements are often the driver for fundamental system design decisions, and they can strongly influence the system functional and physical architecture. Although the consideration of safety objectives may appear initially to slow the process and constrain the set of potential solutions, their inclusion from the first phases of research is the best approach to mitigate technical risk. The ambitious goals set for the AvSTAR project will require system designs radically different from today's, and the process of commissioning and/or certifying the new system will be challenging. The successful implementation will hinge upon a demonstrated safety performance, above all other considerations. *Therefore, it is* *recommended that clear statements about safety be added to the goals, and that appropriate safety modeling and analysis methodologies be integrated into the plan from the start.*

Recommendation 8. Safety goals and metrics should be included explicitly in the goals statement and the project plan.

Another potential system goal to be considered is access. Access to airspace may involve the allocation of airspace use among user categories instrument flight rules (IFR) and visual flight rules (VFR) and associated equipage requirements. Access is viewed to be especially important to general aviation, military, and other user groups.

Recommendation 9. Include access goals for all major airspace users.

Environmental issues must be considered in terms of airport noise and emission levels to be supported in future operations. With traffic growth, these considerations may be increasingly important for technology assessment.

Recommendation 10. Include environmental issues in the goals statement.

Finally, cost is a performance metric that is key to acceptance of new systems and eventual investment by all stakeholders. There is little doubt that given the current NAS performance levels and the predicted growth, the solution to the 2025 performance problem will involve a major investment across the system. This could prove to be the most significant risk to success, particularly if not explicitly accounted for in the goal. In general, the industry is willing to make significant investments, provided that a clear case can be made that correspondingly significant benefits will be derived. Thus, an affordable solution can be one that carries high cost, if the benefits are even higher.

Recommendation 11. Include affordability in the goals statement.

4. Are the Goals Technically Feasible?

Boeing ATM's view of the technical challenges of air traffic growth, as expressed in the June 2001 presentation “Air Traffic Management” [5], is that an engineering solution to address this challenge is technically feasible. The Boeing ATM plan, when combined with the FAA OEP [3], is predicted to accommodate 15 to 17 years of traffic growth in the NAS. Furthermore, when combined with new runway construction and advanced airport concepts, 20 to 25 years of traffic growth can be accommodated. The most significant point of difference between the NASA and Boeing plans is the implementation schedule, which in the Boeing plan targets the initial operating capability of the last system phase in 2008. The NASA target is no earlier than 2015. The Boeing plan explicitly states that additional runway capacity will be required to satisfy the demand, but the AvSTAR project material is silent on this issue.

AvSTAR and the Boeing plan agree on the nature of the change that will be required in ATM. Both plans discuss the need for a radically new paradigm in ATM, one that includes significantly increased levels of automation across the system. It is Boeing's view that NASA's research and development charter in U.S. ATM is unique in its long-term objectives, and that a fundamental research focus on this challenging problem should be a high priority for the U.S. to ensure the viability of its transportation system. U.S. industry has neither the resources nor the required expertise and facilities to perform this research, but stands ready to implement new concepts and technologies as they become mature and can be shown to have significant benefits potential.

In light of the very limited progress made over the last two decades in implementing new technology for ATM, it is clear that significant risks are present that could prevent the system from satisfying the predicted demand. The primary risks, in the authors' opinion, include the following:

- Air traffic controller resistance to increased automation and significantly changed working methods
- Local residential resistance to airport capital investment for increased throughput
- General aviation pilot resistance to more expensive equipment required to operate in high-density airspace
- Airline resistance to invest in new technology and change operating methods, particularly in light of opportunities for existing strong players to profit (without any investment) in a constrained market
- (Related to the last item) Mixed equipage: new operations designed to increase capacity may not be fully exploited when some of the participants do not have the requisite equipment
- Intermodal transportation improvements may not keep pace with traffic growth, thus limiting the public's access to the air transportation system
- Inability to solve the wake vortex problem on final approach, thus making the system even more sensitive to low-visibility conditions than it is today
- Certification of new ATM systems that include complex software and high levels of integration across a large number of agents
- Resistance from current communications, navigation, and surveillance (CNS)/ATM equipment suppliers to potential major changes in system infrastructure that could change that marketplace

This list of risk factors is by no means comprehensive, but all have been active forces in the NAS modernization process over the last decade. To increase the probability of success of the AvSTAR project, *NASA must design and implement a risk management plan with the program, clearly identifying all important risk elements. NASA should address the factors it can include in its research program, and also alert the FAA and the Department of Transportation to critical factors that are outside of NASA's control.* It is in the best interest of NASA, as well as the NAS, to identify and openly discuss all important risk factors. Otherwise, the AvSTAR project may promise results that are unlikely to be achieved because of external factors.

Recommendation 12. Establish a risk management plan for factors both internal and external to NASA.

5. Is the NASA Plan Appropriate for Achieving the Goals in the Allotted Time?

The Boeing team based its efforts at answering this question on AvSTAR project presentation material [1] and on numerous conversations with NASA staff actively involved in planning the project. Given the preliminary and conceptual nature of the more visionary elements of the project, this evaluation had to be performed at a very high level, and a significant amount of expert judgment had to be applied to predicting the likely outcome of each project element. Thus, the results have to be considered as extremely preliminary, and unavoidably biased by the experience and opinions of the individuals on the team. An attempt is made to compensate for this by providing explanatory comments for the assessment of each project element, and it is the hope of the authors that the use of this material be limited to making additions and/or improvements to the definition and execution of the work undertaken during the project.

General Remarks

The AvSTAR project plan assessed in this report, as defined in the March 2001 workshop presentations, is grouped into four major categories: System-Level Concept Development and Evaluation (SLCDE), Tomorrow's Component Technologies, Advanced Component Technologies, and Virtual Airspace System Technology (VAST).

The Tomorrow's Component Technologies area is intended to complete research and development on technologies that were started under the Advanced Air Transportation Technologies (AATT) program, in support of the FAA's midterm performance needs. As such, these technologies were originally constrained to augment the current ATM paradigm by providing incremental automation capability to the current working positions, assuming little or no change in CNS infrastructure. The exceptions are some elements of the Distributed Air-Ground Traffic Management (DAG-TM) concept involving airborne self-spacing, and some data-link capability assumptions.

The SLCDE component includes two key elements: the development of alternate operational concepts and the ability to perform benefits trade studies on these concepts. The plan to develop alternate concepts is the logical first phase of such a program, but few details are provided on how this will be undertaken. The automated airspace concept presented at the workshops is a good first example, and other concepts are presumed to follow. It is not clear to what extent the concept generation activity will be driven by the system performance goals stated for the program, or a less structured set of potential concept variations conceived for the ATM field.

Recommendation 13. The concept development activity should be firmly guided by the system performance goals, particularly throughput and safety.

The evaluation component of the SLCDE effort is vital to the process of discriminating among the various concepts that may be generated. The VAST effort is intended to support this evaluation with an appropriate toolset. In the beginning, the bulk of the VAST effort should support the SLCDE effort, via simulations designed to supply models or parameters needed for the operational concept analysis and broad concept trade studies. This cannot be achieved efficiently with human-in-the-loop (HIL) methodology, but will require a fast-time simulation capability. Only later, for mature, highly promising concepts and technologies, should the VAST project venture into the ambitious enterprise of connecting vast arrays of labs, computing facilities, operational centers, etc. into a large-scale distributed simulation capability.

Recommendation 14. The VAST component should emphasize the development of a fast-time operational concept performance-analysis capability.

The evaluation tools of the SLCDE effort should include the capability to perform trade-offs for safety as well as capacity. In order to estimate the overall system safety, one has to consider the *interactions* of the various subsystems, technologies, and procedures with each other. The fast-time models should include the ability to simulate and quantify the effects of rare-normal and abnormal behavior. The VAST real-time high-fidelity HIL modeling can be used to investigate human factors issues and provide parameters and behaviors for the fast-time overall system models.

Recommendation 15. The VAST component should include an ATM safety-analysis capability, including representation of human performance elements.

The government/industry workshops have included all the stakeholders and have contributed to an understanding of other stakeholders' points of view. It is clear that NASA is addressing feedback from the other industry stakeholders. In the March 2001 workshop, for example, the NASA presentations contained responses to the comments and questions from the previous workshop.

Detailed Program Task Assessment

In this section, specific tasks of the AvSTAR program are evaluated based on their contribution to the overall program goals. The tasks are defined in the March 2001 workshop presentations, and are grouped into four major categories: SLCDE, Tomorrow's Component Technologies, Advanced Component Technologies, and VAST.

Each task element is assessed for its potential contribution (assuming the end product is implemented) to the capacity and safety of the NAS. Capacity and safety assessments are based on the apparent emphasis in these areas by the material provided in the NASA AvSTAR plan, and the authors' understanding of the likely content of the work statement.

The cost of the end product of each task element is evaluated, based on a purely relative and qualitative best-judgment estimate of the investment cost to the air traffic service provider (ATSP) and airspace users, as well as the potential reductions in operations and maintenance cost. These cost evaluations are based solely on the authors' assessment of their potential effect on the NAS, because the AvSTAR program material does not yet address these performance metrics. Note that a High rating for cost is not necessarily a detriment, because significant performance increases can be expected to require an equally significant investment.

A rating of N/A was used numerous times, to indicate that a task either had no relevance to the metric, or that insufficient information was present to make an evaluation.

Finally, whenever possible, additional explanation or clarification is provided, in the form of remarks.

<u>System-Level Concept Development and Evaluation</u>
Key Element 1.
Develop integrated methods for system-level analysis: investigate, develop, validate, and document methods for model-based system-level analysis; human system modeling; and analytic methods for hybrid systems, including human and team modeling.

Capacity: High

Safety: High

Operational and Maintenance Cost Reduction: Possible, if explicitly targeted.

Investment Cost to ATSP and Users: N/A

Remarks:
This capability is intended to reduce the CNS/ATM industry's reliance HIL experimentation for early concept development, which tends to take a long time from initial research to implementation in the field. This toolset has the potential to include safety assessment in early concept studies, including the role of the human operators, which can help ensure that automation technologies can be certified when ready for deployment, even for reduced traffic-separation standards. It will enable efficient development of a new air/ground integrated ATM paradigm. There is also a potential to reduce ATSP operations cost if targeted by the research.

Recommendation 16. Increase the emphasis on, and therefore the budget for, the SLCDE portion of the program.

Key Element 2.
Gather, sustain, and analyze operational concepts: identify and define concept evaluation criteria and conduct concept feasibility trade-off evaluations.

Capacity: Medium

Safety: Medium

Operational and Maintenance Cost Reduction: Possible, if explicitly targeted.

Investment Cost to ATSP and Users: N/A

Remarks:
This needs to be performance driven, rather than a random collection exercise across the entire spectrum of potential concept parameters. The key is the ability to evaluate and select the concepts with the highest potential against the most important system performance metrics. Thus structured, this would get high marks for capacity and safety.

Recommendation 17. Focus the concept development process on achieving the most important system performance objectives.

Key Element 3.
Validate and recommend candidate concepts for the NAS: infrastructure characterization; traffic scenario generation; HIL simulation; batch simulation; translation to nationwide performance; and benefits and impact analysis. This will make use of the VAST capability.

Capacity: High

Safety: High

Operational and Maintenance Cost Reduction: Possible, if explicitly targeted.

Investment Cost to ATSP and Users: High

Remarks:
As in Key Element 1, safety analysis should be integrated into this element. For example, HIL simulation can be used to derive performance and error-rate parameters for the batch simulations. The overall simulations should consider the safety implications of various interfaces (e.g., sector-to-sector, human-machine, pilot-controller) and how they are affected when new operational procedures or technologies are introduced.

Key Element 4.
Transfer analysis products to the FAA: identify and document AvSTAR transition approach.

Capacity: N/A

Safety: N/A

Operational and Maintenance Cost Reduction: N/A

Investment Cost to ATSP and Users: N/A

Remarks: The metrics do not really apply in this case. However, risk assessment of implementing any of the technologies is strongly encouraged, and the plan can be structured to reduce this risk.

Tomorrow's Component Technologies
Key Element 1.
Surface congestion alleviation: surface movement decision support tools (DSTs), advisories; displays; and data link.

Capacity: Low

Safety: Medium

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: Medium

Remarks:
Safety benefit depends upon successful inclusion of runway incursion-prevention functionality.

Key Element 2.
Runway productivity: Aircraft Vortex Spacing System (AVOSS) and Airborne Information for Lateral Spacing (AILS); AILS submitted as "over-guideline" budget request

Capacity: High

Safety: High

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: High

Remarks:
AILS and AVOSS have the potential to increase capacity and safety if they achieve user acceptance.

Key Element 3.
Arrival/departure decision support tools: Center/TRACON Automation System (CTAS), active Final Approach Spacing Tool (aFAST), Expedite Departure Path (EDP); DAG-TM, dynamic routing and spacing; interdependent arrival/surface advisories; airborne

self-spacing; and environmentally compatible operations; dynamic routing and environmental compatibility will be taken to TRL 4 only

Capacity: Medium

Safety: N/A

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: Medium

Remarks:
This element includes a large collection of AATT technologies, most of which were developed assuming the current control paradigm. Although these tools will not provide significant increases in capacity when installed within the current control paradigm, they are an essential step in moving toward a more automated airspace that has a potential for capacity gains. DAG-TM (in particular, concept #11) has a potential for providing capacity gains via reduction of separation, and individually would be rated High in the Capacity category. The safety benefit cannot be assessed because no analysis has been provided by the AATT project.

Key Element 4.
Integrated airspace decision support tools: en-route descent advisor (EDA); direct-to tools; regional flow metering; constrained airspace tool; air traffic control/Airline Operations Center (ATC/AOC)/flight-deck integration. The spacing tool is dropped, and regional flow metering work is accelerated (will make miles-in-trail obsolete).

Capacity: Medium

Safety: N/A

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: Medium

Remarks:
See the previous element. En-route airspace in the U.S. is not a significant capacity constraint, except in cases of significant convective weather activity. Although the most severe delays occur during these periods of adverse weather, such periods are relatively infrequent. As a result, even the most effective combination of strategies and/or tools would result in a medium capacity improvement at best. The authors think a proper combination of the constrained airspace tool (which would help in convective weather en-route situations) and the ATC/AOC/flight-deck integration (which would help reduce sector workload) has a potential for providing a Medium capacity improvement.

Key Element 5.
National traffic flow management: Traffic Flow Automation System (TFAS) and Future ATM Concepts Evaluation Tool (FACET). TFAS is consolidated under AATT; this activity is integrated with related FAA activities through the Inter-Agency Integrated Product Team (IAIPT) (Mitre Center for Advanced Aviation System Development (CAASD) and Volpe).

Capacity: Low

Safety: N/A

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: Low

Remarks:
The element should contribute to the delay and cancellation reduction goals, particularly related to weather-induced capacity constraints.

Key Element 6.
Small airport utilization: the cost of this new activity is currently $3.5 million.

Capacity: More access for general aviation (GA).

Safety: Medium improvement for GA.

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: Medium

Remarks:
More access for the GA user segment may pose an increase in load on the overall ATM system beyond that predicted by growth in commercially scheduled operations. Thus, traffic growth predictions must be accounted for in this segment of the user class.

Key Element 7.
Runway-independent aircraft (A/C) operations: simultaneous noninterfering (SNI) operations; vertical/short takeoff/vertical landing (V/STOVL) operations; low noise; missed approaches. Submitted as an "over-guideline" budget request, this element has been split into SNI and adverse weather/low noise operations; it will be integrated with FAA plans in GA and vertical flight technology.

Capacity: Medium

Safety: Low

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: High

Remarks:
Runway-independent operations and simultaneous operations may reduce traditional safety margins and, therefore, need compensating technologies and/or procedures. Low-noise approaches achieved via approach-path modifications involve increased complexity during a time of high workload. V/STOVL operations introduce a dissimilar element into a heretofore fairly homogenous environment. Therefore, the components of this key element need a careful and extensive safety analysis. The overall CNS/ATM infrastructure for V/STOVL operations needs significant improvement, including airspace and procedure design criteria, which will be costly.

Key Element 8.
ATM/traffic flow management (TFM) weather integration: focal point for all weather requirements for decision support tools (DST).

Capacity: Medium

Safety: Medium

Operational and Maintenance Cost Reduction: Low

Investment Cost to ATSP and Users: Medium

<u>Advanced Component Technologies</u>
Key Element 1.
ATM automation technologies: real-time system optimization; four-dimensional (4-D) optimized ATC in terminal area; increased traffic density/reduced sector boundary constraints; automated A/C separation using DAG conflict detection/resolution; high-level automated traffic flow control. DAG concepts and aircraft self-separation are included.

Capacity: High

Safety: Low

Operational and Maintenance Cost Reduction: High potential to reduce ATSP operations cost if targeted by the research.

Investment Cost to ATSP and Users: High

Remarks: This element needs to focus on good design principles to keep complexity in check, as well as a thorough safety analysis. The plan appears to have insufficient safety-related content to address the significant safety and certification issues. Overall, the concept is very promising from system capacity and affordability points of view.

Key Element 2.
Controller/pilot/system human factors in a highly automated airspace: roles and responsibilities; supervisory control and goal setting; human interface requirements; advanced en-route and terminal automation; advanced surface ATM automation; interfaces for automation-assisted flight planning and communication.

Capacity: High

Safety: High

Operational and Maintenance Cost Reduction: Medium

Investment Cost to ATSP and Users: High

Remarks:
Include consideration of human factors issues, especially for system safety aspects. The high marks are for including human factors in the project from the concept stage, because it is expected that this will force a focus on safety in nonnormal operating modes from the start.

Key Element 3.
Information infrastructure technologies: CNS technologies; information system architecture; requirements for ATM information flow; development and assessment of candidate architectures; identification of technology "gaps".

Capacity: High

Safety: Low; not enough emphasis

Operational and Maintenance Cost Reduction: Potential, if NAS architecture can be simplified and a significant number of old infrastructure elements decommissioned.

Investment Cost to ATSP and Users: High

Remarks:
A potential risk element here is that it will require a radical change in the FAA architecture, with associated certification challenges.

Key Element 4.
Improved utilization of airports/limited airspace: meta-airport operations; closely spaced operations; dynamically configurable runways/taxiways; zero-visibility surface

movement; virtual tower; airport robotics. This element would attempt to challenge the one-aircraft-per-runway rule.

Capacity: High+

Safety: Medium

Operational and Maintenance Cost Reduction: N/A

Investment Cost to ATSP and Users: High

Remarks:
This element needs an integrated safety analysis because there are so many interacting components and aircraft density is higher around airports. This has the highest potential for capacity increase of all tasks, assuming the primary bottleneck is the runway.

Virtual Airspace Simulation Technology (VAST)
Key Element 1.
Create a virtual research environment: remote accessibility to labs, and simulation environments.

Capacity: N/A

Safety: N/A

Operational and Maintenance Cost Reduction: N/A

Investment Cost to ATSP and Users: N/A

Remarks:
Some distributed simulation capability may be useful for AvSTAR, but in the later stages of the project to support the technology transfer process. This element will be very costly to establish, and very costly and time-consuming to perform experiments and demonstrations, so it is not appropriate for concept exploration and early stages of research.

Key Element 2.
Link existing and future simulation concepts: software emulations and HIL simulation facilities.

Capacity: N/A

Safety: N/A

Operational and Maintenance Cost Reduction: N/A

Investment Cost to ATSP and Users: N/A

Remarks:
The HIL simulations can provide valuable data to fast-time simulations, and thereby contribute to safety if the fast-time simulations include rare-normal and abnormal behaviors.

Key Element 3.
Establish network architecture: link multiple facilities/capabilities in reconfigurable groupings. Initial work will establish the requirements for this architecture.

Capacity: N/A

Safety: N/A

Operational and Maintenance Cost Reduction: N/A

Investment Cost to ATSP and Users: N/A

6. Summary of Assessment and Recommendations

The authors commend the AvSTAR project planning team at NASA for the following important aspects of the current plan:

- a statement of the ATM system throughput needs through 2025, in the form of quantifiable goals for this research project;
- a significant emphasis on quantitative assessment of proposed new operational concepts, and an ambitious plan to establish a new, fast-time capability to perform such assessment early in the project; this will enable NASA to select the most promising new ATM concepts based on system performance goals, thus focusing research clearly on NAS performance;
- presentation of a possible new ATM paradigm that has the potential to significantly increase the system capacity and affordability, along with a plan to generate numerous other new concepts; and
- explicit involvement of all government and industry stakeholders in the project definition phase, by hosting two major workshops to present NASA's ideas and solicit stakeholder input.

As discussed in more detail in earlier sections of the report, the authors recommend the following revisions to the current AvSTAR plan:

Recommendation 1. Revise the 2-percent growth assumption in the goals statement related to projected increases in future traffic demand.

Recommendation 2. The schedule is aligned with the growth assumption. However, a clearer distinction needs to be made between the NASA research goals and the NAS implementation goals.

Recommendation 3. Clearly define the metrics used for goals.

Recommendation 4. Link the throughput goals to metrics of passenger (and other user) preferences and include studies to quantify performance against such metrics.

Recommendation 5. Look at a range of potential future scenarios, and tailor the goals and project plan to accommodate them.

Recommendation 6. Performance goals for particular operating regions need to be based on a total system performance analysis and an allocation of performance requirements to each operating region.

Recommendation 7. Define performance goals for particular operating conditions, such as IMC Category I, II, and III, and convective weather. These goals should be as close as possible to the VMC goals, and they should be derived from the delay and cancellation goals.

Recommendation 8. Safety goals and metrics should be included explicitly in the goals statement and the project plan.

Recommendation 9. Include access goals for all major airspace users.

Recommendation 10. Include environmental issues in the goals statement.

Recommendation 11. Include affordability in the goals statement.

Recommendation 12. Establish a risk management plan for factors both internal and external to NASA.

Recommendation 13. The concept development activity should be firmly guided by the system performance goals, particularly throughput and safety.

Recommendation 14. The VAST component should emphasize the development of a fast-time operational concept performance-analysis capability.

Recommendation 15. The VAST component should include an ATM safety-analysis capability, including representation of human performance elements.

Recommendation 16. Increase the emphasis on, and therefore the budget for, the SLCDE portion of the program.

Recommendation 17. Focus the concept development process on achieving the most important system performance objectives.

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Appendix A. Definitions of Demand, Capacity, Throughput, and Delay

The terms used to describe how much traffic the air transportation system can handle are often used interchangeably, and with different interpretations by different individuals. To avoid miscommunication, the following definitions used in this report are recommended to NASA:

Demand is the number of aircraft per unit of time attempting to pass through an airport or some specified volume of airspace. This quantity, for airports, is estimated in the Current Market Outlook (CMO) based on assumptions about economic growth and airline business and operational strategies.

Throughput is the number of aircraft per unit of time actually passing through an airport or a given volume of airspace. The most commonly used time units are quarter hour, hour, and day. Throughput is easily recorded by simply counting the number of operations at a location in a given time period, and clearly depends on the presence of traffic demand.

Delay can be defined as the difference between scheduled and actual times at some specified point (runway threshold or gate, for example). Delay can be measured relatively easily by recording times at defined positions.

The primary practical difficulty with delay measurement is that the airlines tend to manage their schedule (e.g., with larger block times) to reduce the operational impact of likely delays. In fact, reported average delays, as measured against the airline schedule, have not changed much in a decade [6]. The consumer-oriented on-time arrival reporting system has almost certainly contributed to this effect. *Consequently, there is a significant buffer built into the flight schedule, which represents a significant cost in terms of equipment and manpower utilization and is difficult to account for using a traditional operational delay analysis.*

On the other hand, as the U.S. National Airspace System (NAS) reaches saturation, events such as weather perturbations can cause large, widespread delays that attract a lot of media attention. Therefore, it might be beneficial to focus some attention on reducing the *sensitivity* of the system to such perturbations, so that the large variations in delay do not occur, or at least occur less often.

Capacity can be defined as the maximum theoretical throughput of the whole system, or of subsets of the system such as airports or air traffic control sectors. System capacity is a quantity of interest because it represents a theoretical limit on what might be operationally achievable.

The actual computation of system capacity requires a sophisticated analysis of the air traffic network, including an assessment of the capacity of the human operators to handle traffic demand under some ideal and nonideal conditions. There would be several different capacity results, depending on the assumptions made about components of the system, external factors such as weather, and demand levels.

Nevertheless, it is possible to approximate the relationship among demand, capacity, and delay by making some simplifying assumptions. In particular, assume the system (NAS, terminal area, or airport, for example) can be modeled as an M/M/1 queue (single-server system with infinite storage capacity and exponentially distributed inter-arrival and service times) [7]. This is a major simplification, but it illustrates some of the phenomena that would be present in a more complete analysis.

In this model, let λ be the arrival rate of aircraft (demand) and μ be the service rate. Let $\rho = \lambda/\mu$, the traffic intensity. Then a standard result from queuing theory [7] says that the average waiting time in the system is given by

$$W = \frac{\rho}{\lambda(1-\rho)} = \frac{1}{\mu - \lambda}$$

Note that $\lim_{\lambda \to 0} W = \frac{1}{\mu}$, which says that, when demand is very low, the average waiting time is the average service time, which is what would be expected. Define the delay D in this simple model to be the excess of the waiting time over the average service time; that is,

$$D = W - \frac{1}{\mu} = \frac{\rho}{\mu - \lambda}$$

Figure A-1 shows a plot of delay D vs. demand λ in this simple queuing model. Clearly, delay is very sensitive to demand in the region where demand rate is close to the average service rate. This illustrates the well-known phenomenon of rapidly escalating delays in a system that experiences even a small increase in demand while operating close to capacity.

Figure A-2 shows two plots, one for each of two different values of the service rate μ. Also, the two service rates have been relabeled as current NAS capacity and future NAS capacity. Note the vertical and horizontal line segments bounded by the two curves. The horizontal line segment represents the increase in demand at a given delay level made possible by the capacity increase. The vertical line segment represents a decrease in delay at a given demand level made possible by the capacity increase. If traffic demand is not increasing, a capacity increase should thus result in lower delay. If, however, demand is increasing, the system should observe a higher level of actual throughput, with delay levels possibly not significantly reduced.

Whether or not an increase in capacity will lower delay levels or increase throughput is ultimately determined by the demand from the system users.

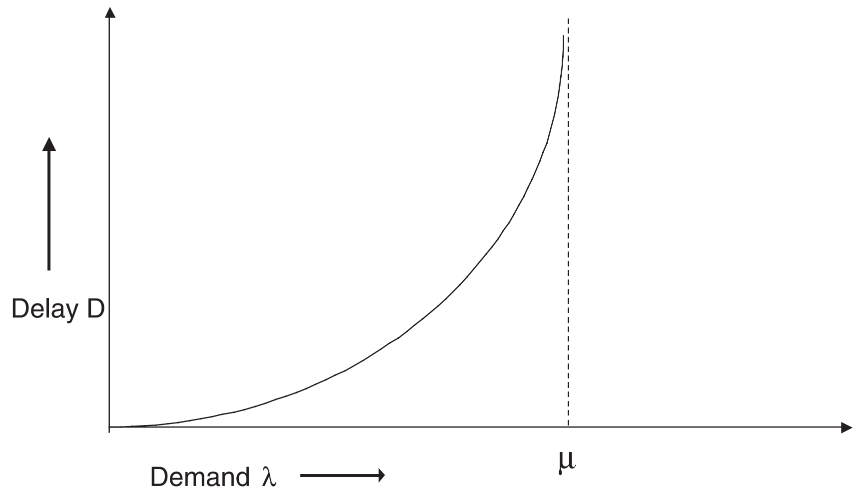

Figure A-1. Delay vs. demand in the simple queuing model.

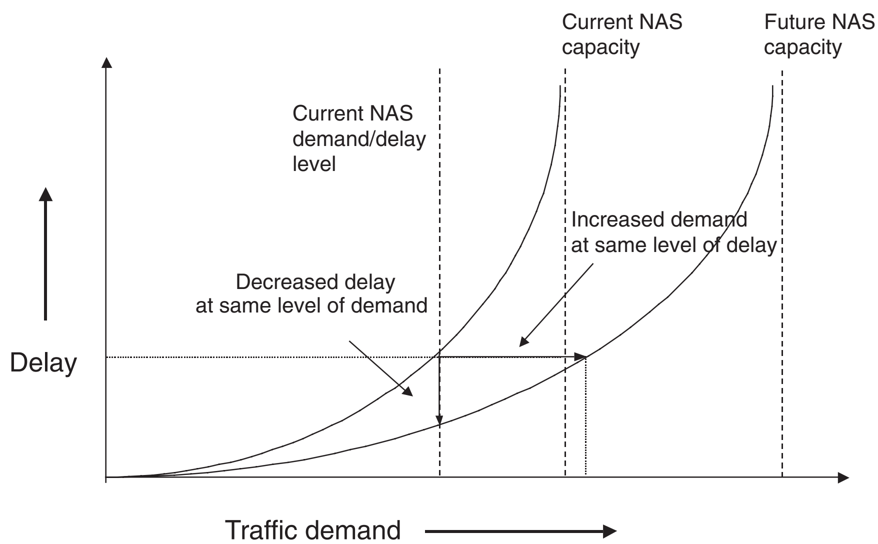

Figure A-2. The basics: demand, capacity, and delay.

Appendix B. Airline Schedule Quality Issues in Air Traffic Management

B.1 Objectives

A variety of measures of effectiveness have been employed for use in comparing alternative air-traffic-management (ATM) systems. An important one, which has received less attention than others, is airline schedule quality. This refers to schedule quality from a passenger point of view, and refers primarily to the ability of the airline schedules to offer sufficient travel opportunities in the places and at the times that they are needed. It is a long-term objective at Boeing to analyze and quantify the relationships that exist between air traffic system capacity and the resultant airline schedule quality. The preliminary analysis shown here is a first step in this direction and makes use of the following:

- the Boeing airline schedule-generation capability developed for ATM concept evaluation, described in section B.2; and
- a simple schedule quality metric developed to explore schedule quality issues under alternative air traffic system growth scenarios, described in section B.3.

B.2 Overview of Future Airline Schedule-Generation Methodology

An approach has been developed and exercised for creating future scheduled airline flights suitable for ATM concept analysis. Although this approach was developed and implemented prior to the work performed under this contract, it plays an important role in the schedule quality analysis shown in this section. The approach relies on:

- projections from the Boeing Current Market Outlook (CMO);
- an analysis of existing schedules as represented by the Official Airline Guide (OAG); and
- algorithms for realizing the future schedules in an optimal way; a high-level view is shown in Figure B.2-1 and is explained in the following paragraph.

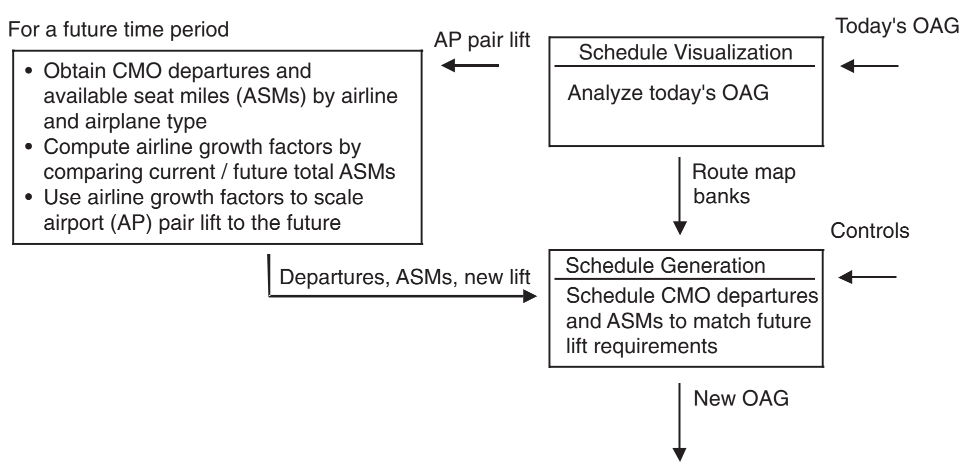

Figure B.2-1 Future airline schedule methodology.

The future schedules created thus far are for all flights in or out of the contiguous United States and are based upon the CMO traffic-forecasting process. This process utilizes an analysis of the current OAG and creates forecasts for various future years up to and including the year 2020. The model uses CMO forecasts of departures and available seat miles (ASMs) by equipment type and major airline. For this analysis, ten major U.S. airlines were explicitly considered with three aggregated carriers for cargo, foreign, and other U.S. carriers. The forecast showed a 77-percent increase in total departures from year 2000 to year 2020 with an average flight distance increase from 688 miles to 696 miles, and with an approximate increase from 173 seats per mile flown to about 179 seats per mile flown. Thus, this baseline CMO forecast projects the vast majority of future demand to be met by increased frequencies, as opposed to being met by larger aircraft.

Although the CMO forecast provides the total number of departures by equipment type and major airline, it does not indicate the assignment of these departures to particular nonstop airport pairs. In order to perform this assignment we must calculate the “lift” (i.e., number of seats) to be allocated to each such airport pair for the future time period. The set of nonstop airport pairs for an airline is called its route map. An analysis of existing schedules is first used to identify the segment route map for each major airline and, for each airport pair in the route map, the lift currently allocated to that pair. The future required lift for an airline airport pair is then calculated by projecting its current lift into the future by a factor computed from the ratio of the total CMO forecast ASMs divided by the total current ASMs for that airline. *This assumes for each airline that there are no new nonstop airport pairs and that each existing pair grows at the same rate.* The existing schedules are also analyzed to uncover the bank structure employed at each major airline hub. *It is assumed that this bank structure will remain the same in future time periods, although the maximum bank sizes will be permitted to grow.*

When the future lift requirements (by airport pair and airline) are calculated, then an allocation process is undertaken to assign the forecast CMO airline/equipment departures to the individual airport pairs. The objective is to match as closely as possible both the required future lift on each airport pair and the forecast ASMs to be flown by each type of equipment for the given airline. This must be accomplished while respecting the design range limitations of the equipment. The departures (or arrivals) assigned to the hubs are then allocated to the airline banks in order to maximize schedule quality, using the Boeing Decision Window Model (DWM) as applied to the local markets, while respecting the maximum bank sizes and flow conservation. The last step in the process is to finalize the departure and arrival times for all flights (by any airline) while observing an airport specific limitation on the number of operations (takeoffs or landings) that may occur in any five-minute time window. Again, DWM is used to help select departure times based on schedule quality considerations. Depending on the scenario being evaluated the airports may be allowed to grow in their ability to process takeoffs and landings. When there is growth it is then assumed that the maximum bank sizes will grow correspondingly.

Although it is believed that this schedule-generation capability is unique in the industry, there are some areas for investigation and future development in order to improve upon the process. These areas include consideration of the following factors:

- new nonstop airport pairs, including airports that are currently not in the OAG;
- efficient, tail-routable schedules in order to better account for delay propagation through the airline networks;
- redefined airline bank structures;
- alternative CMO forecasts; and
- schedule quality issues: the last of these areas is concerned with the fact that schedules created under alternative airspace constraints will not generally result in schedules of corresponding quality. The simple schedule quality indicator and preliminary analysis discussed in section B.3 represent a first look at this issue.

B.3 A Simple Schedule Quality Indicator

The analysis in section B.4 makes use of a simple schedule quality indicator. It is based upon time-of-day demand relationships developed and used in Boeing's DWM of passenger path preference. Critical input to DWM are the arrival and departure "indices" or "weightings" illustrated in figure B.3-1. They show the relative desirability of departure times and arrival times as a function of the (local) time of day. In general, the desirability of flying at some time of day is a function of both the departure and arrival weightings. For this analysis we define "bad" departure hours and "bad" arrival hours to be the five worst hours of the day, respectively. Thus, as illustrated in figure B.3-1, the bad departure hours are 2–6, whereas the bad arrival hours are 1–5. We will label a flight as "bad" if either its departure *or* arrival time is bad. Then, for a given schedule, we will measure the fraction of seats on bad flights. Thus, our simple measure of schedule quality will actually be a measure of schedule "badness".

A metric as simple as this one has some issues. First, some (very) small fraction of travelers might actually *prefer* the bad departure or arrival times. Second, and much more important, not everybody would prefer just *any* "good" flight. In this context, good flights are anything not labeled bad. For example, a passenger might be satisfied by a morning flight but not an afternoon flight, even though both were labeled "good". The important consequence is that if a schedule badness of 4-percent is calculated, for example, that does *not* mean that schedule "quality" is 96-percent. The intent is to capture an indication of schedule quality deterioration. That is, when a new schedule is created subject to air traffic capacity constraints, if an increase in schedule badness relative to today's schedule is observed, it can be concluded that there is a likely deterioration in schedule quality. This is why the bad departure and arrival hours have been selected so that they are *very* bad.

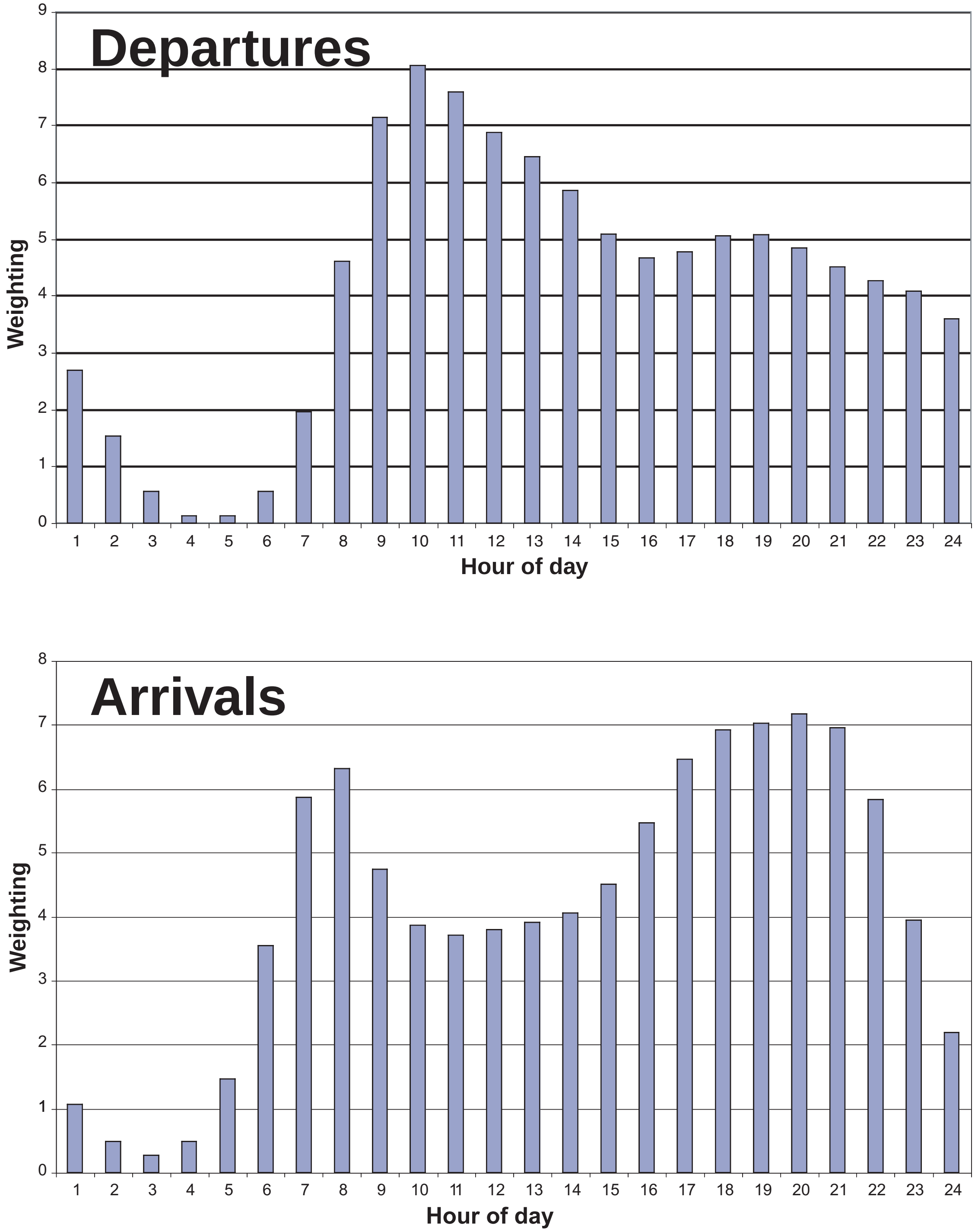

Figure B.3-1 Departure/arrival weightings vs. time of day.

B.4 Preliminary Schedule Quality Analysis

The objective of this preliminary analysis is to compute the simple schedule "badness" measure for alternative scenarios representing different assumptions concerning air traffic capacity. This capacity is expressed simply as a maximum number of arrival/departure operations for any five-minute period at an airport, based on the hourly airport capacity. Schedules are generated for some future time period subject to these constraints and are then evaluated. The following scenarios have been explored:

OAG – year 2000 actual schedules as published by each airline
BL – year 2000 generated schedules, using the methods described in section B.2
NG – year 2020 generated schedules, no ATM capacity growth
RG – year 2020 generated schedules, nominal runway growth
AG – year 2020 generated schedules, Aviation System Technology Advanced Research (AvStar) program "goal" growth
IG – year 2020 generated schedules, infinite ATM capacity

For each of these scenarios various subsets of flights were evaluated:

SYS – the entire (U.S. domestic) system of flights
ORD – the subset of SYS involving ORD (Chicago O'Hare) flights
ATL – the subset of SYS involving ATL (Atlanta) flights

Baseline airport capacities were specified for the top 100 U.S. airports, as published in the Federal Aviation Administration (FAA) Capacity Baseline Report [8]. The remaining airports were given a maximum capacity of 60 operations per hour (or a maximum of 5 operations per 5-minute period). The NG scenario assumes the same airport capacities (in 2020) as are employed in the baseline scenario. The RG scenario assumes airport capacities are increased in accordance with forecast additional runways [8]. ORD was selected because it was an airport without forecast runway growth, whereas ATL was selected because an additional runway is planned to handle growth in this time frame. *The AG scenario assumes 2-percent annual growth from the baseline over a 20-year period, according to the AvSTAR goal assumptions. This was applied to the top 100 airports with no growth assumed for all remaining airports.*

Figure B.4-1 shows the fraction of airport capacity utilized as a function of hour of day for ORD. Results for this graph were aggregated to the one-hour level (versus the five-minute level) to smooth the results. The graph compares the BL and NG scenarios and indicates a shift of airport use into the early morning hours given the insufficient airport capacity, along with a filling-in of the times between traffic peaks. Results such as these motivated the creation of the schedule badness metric. Note, also, that the scheduled flying exhausts all available capacity during the daylight hours for the NG scenario. Under this scenario there will be little opportunity to recover during the day after disturbances such as weather or system outages that temporarily reduce capacity.

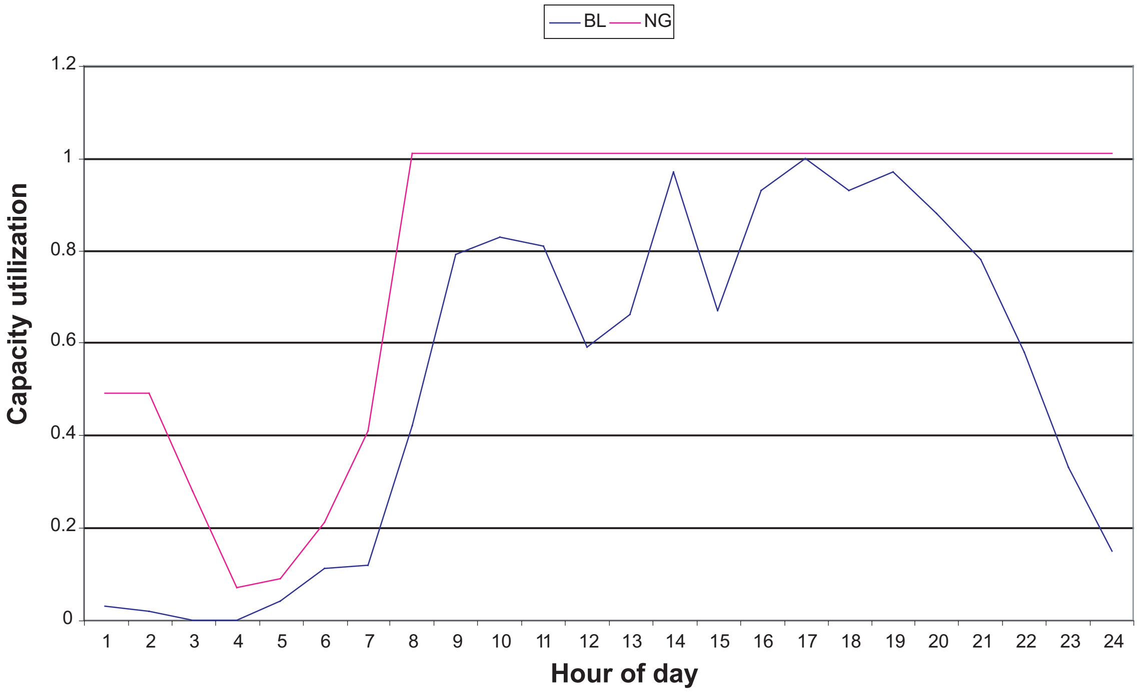

Figure B.4-1 Capacity utilization at ORD—2020.

Figure B.4-2 shows the schedule badness evaluations for the various cases under consideration. As expected, the OAG, BL, and IG cases are nearly the same in terms of this measure, particularly given the complexity of the schedule-generation process. There is, however, a distinct difference between these cases and the NG case. The significant increase in schedule badness for the NG case is a strong indicator of schedule quality deterioration due to insufficient airport capacity. The additional runways for the RG case (currently planned new runways) offer only slight relief for SYS and ATL and none for ORD. The AG case (AvSTAR goals) is also indistinguishable from the OAG, BL, and IG cases. *This indicates that a 2-percent annual growth at the top 100 airports may be adequate to meet future needs. The authors believe, however, that more detailed analysis is needed to confirm that conclusion.* Schedule badness was constructed so that when a problem is indicated it is a sure sign of schedule quality deterioration but “no indication” does not necessarily mean that schedule quality has been completely maintained.

	OAG	BL	NG	RG	AG	IG
SYS	0.02	0.01	0.09	0.07	0.02	0.02
ORD	0.02	0.03	0.11	0.12	0.04	0.04
ATL	0.03	0.02	0.12	0.05	0.03	0.02

Figure B.4-2 Preliminary results – schedule "badness" indicator.

B.5 Forecasting Issues and Next Steps

The primary issue in this analysis is that the schedule badness indicator is not a sufficient measure of schedule quality. A true measure of schedule quality would determine the fraction of passenger demand that could be satisfied by the schedule. This index must account for, as a minimum:

- origin-destination demand (connect paths);
- time-of-day demand and schedule tolerance throughout the day;
- passenger behavior (e.g. path-class choice); and
- demand variability, airplane capacity, and revenue management.

The schedule badness indicator captures only a small part of the time-of-day demand effects and the associated distribution of scheduled capacity, namely the undesirable hours in the middle of the night. It makes an implicit "local-demand-only" assumption in the sense that all seats on bad flights count as bad even though some of them will belong to connecting passengers. There are also some issues with the schedule-generation process, previously discussed in section B.2. Those issues are inherited in this analysis.

Additionally, in the NG and RG cases, some flights forecast by the CMO could not be scheduled at all because of a lack of airport capacity. This is really an indication that the CMO forecast is inconsistent with the no-growth scenario. In reality, the airlines would adapt their scheduling and even business strategies to highly constrained airport capacities. In the future, alternative CMO forecasts should be developed to more closely match the various assumptions on airport or air traffic system capacity. It might also be advisable to explore more complex representations of airport capacity, particularly schemes allowing for a differentiation between peak and average capacities.

In terms of schedule generation, Boeing's future activities will focus on at the creation of alternative CMO forecasts, development of efficient tail-routable schedules, consideration of alternative bank structures, and the development of origin-destination demand-driven airport-pair lift requirements. This last point would also include consideration of the policy questions leading to the inclusion of new “direct-fly” airport pairs. Boeing's efforts concerning schedule evaluation will focus on continued exploration and development of intermediate-level measures of schedule quality. The goal will be to develop an easy-to-understand and practical-to-compute approach applicable to large-scale analysis.

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14. ABSTRACT
This report is a preliminary evaluation of NASA's proposed Aviation System Technology Advanced Research (AvSTAR) Program during the early stages of its definition, in the first half of the year 2001. This evaluation focuses on how well the program goals address the needs of the U.S. National Airspace System, the technical feasibility of the program goals, and the logistical feasibility of the program plan. This report also provides recommendations on how the AvSTAR program could be strengthened and improved.

This document has two appendices.

15. SUBJECT TERMS
NASA, AvSTAR, Air Traffic Management

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